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PERSPECTIVES ON PRACTICAL ASPECTS OF
TRUCK ROUTING AND SCHEDULING

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PERSPECTIVES ON PRACTICAL ASPECTS OF TRUCK ROUTING AND SCHEDULING*

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ABSTRACT

Truck routing and scheduling problems are differentiated from other vehicle routing and scheduling problems and a classification scheme for the former ones is outlined. Many characteristics of practical truck routing and scheduling problems are listed and several aspects are discussed, among them are: soft constraints, demand variability, multiple objectives, complex cost functions, and alternate solution approaches and their potential for solving practical problems. It is suggested that cost-based interactive heuristics coupled with graphical presentation of solutions may be the right method to deal with the more complex practical problems. Some basic generic heuristics are suggested and important software design and acquisition considerations are presented.

1. Introduction

All over the world public and private organizations operate fleets of road vehicles, and each of them faces vehicle routing and scheduling problems. The term routing refers to planning the route that each vehicle will take, and the term scheduling refers to planning the time when each event in a route should take place. The term dispatching encompasses both routing and scheduling, and often includes reacting to unforeseen changes in the plans due to actual conditions encountered during their execution.

There are several major classes of road vehicle routing and scheduling problems which differ significantly from each other in their operational environment and objectives, and within each one of these classes there may be a wide variety of considerations:

1. Passenger transportation
   a. Bus lines - which operate according to a published timetable, with the demand for their services dependent upon that timetable and the routes.
   b. Taxicabs - which respond to demand that arises randomly in a specific geographical region.
   c. Dial-a-ride - which resembles a combination of a bus line and taxicabs. Trips are generated by random demands but segments of them may be shared by more than one demand.
   d. School buses - where demand is known and must be satisfied within a relatively short period of time.

2. Service Operations

   a. Repairmen routing and scheduling - where the effective constraint is time away from base (and not vehicle capacity).

   b. Public Services - such as snow removal, garbage collection, mail delivery, street sweeping and meter reading, in which arcs in a road network must be covered a given number of times in a given orientation.

3. Truck routing and scheduling or cargo transportation which is the focus of this work. This class of problems is concerned with delivery and/or pick-up of goods, and is faced by every truck fleet operator.

A very large body of modeling literature has been devoted to truck routing and scheduling problems (see for example, Bodin et al. (1983)), but most of it has concentrated on hypothetical problems and disregarded many practical aspects of such problems. On the other hand, many practical problems have been tackled (as evidenced by the amount of software packages available for this class of problems, see Golden et al. (1986)), but relatively little has been published about them. Some, relatively recent, practical applications were described by Brown et al. (1987), Belardo et al. (1985), Bocxe and Tilanus (1985), Evans and Norback (1985), Bell et al. (1983), Stacey (1983), Cheshire et al. (1982), Fisher et al. (1982) and Brown and Graves (1981).

The objective of this work is to present various practical aspects of truck routing and scheduling problems, and to suggest ways to deal with them. The following section discusses major classification criteria for these problems, then relations to other distribution planning problems are presented. Practical aspects of truck routing and scheduling problems are examined in section 4, followed by suggested means to tackle them. Finally, software design considerations are provided.

2. Classification of Truck Routing and Scheduling Problems

The large variety of truck routing and scheduling problems necessitates a tool to classify them into different categories of "standard" problems. Such a tool may facilitate communication among researchers and practitioners, and may help to focus research on types of problems which have received little attention. Bodin and Golden (1981) outlined a classification scheme for vehicle routing and scheduling problems, which appeared later in a revised form in Bodin et al. (1983). That scheme covers many aspects of vehicle routing and scheduling problems and will not be repeated here. Rather, a more focused scheme for truck routing and scheduling problems follows (it is assumed that truck capacity is constrained by weight and volume):

1. Fleet size
   a. One truck
   b. More than one
2. Fleet mix - physical characteristics
   a. Identical trucks
   b. Different types of trucks
3. Fleet mix - cost structure
   a. Identical costs for all trucks
   b. Different costs (but same cost structure)
   c. Different cost structures
4. Cost Components
   a. Truck routing cost (set-up cost and variable cost per hour, mile, stop, tolls)
   b. Fleet ownership cost (sunk cost)
   c. Carrier truck cost (variable: miles, hours, stops, tolls, point to point; guaranteed work/minimum charge)
   d. Common carrier cost (point to point by shipment size)
   e. Product sourcing costs

5. Number of truck depots
   a. Single
   b. Multiple
6. Nature of demand
   a. Deterministic
   b. Stochastic demand size (weight, volume)
   c. Stochastic demand location or time
   d. Partial satisfaction of certain demands permitted
7. Type of operation
   a. Delivery only
   b. Pick-up only
   c. Mixed - separated (pick-ups only after deliveries or vice versa, e.g., backhauls)
   d. Mixed - interwoven
8. Number of trips per truck per planning period
   a. One
   b. Multiple
   c. A trip may extend beyond one period.
9. Truck route time
   a. Limited - all trucks have the same limit
   b. Limited - not all the same limit
   c. Not limited
10. Road network
   a. Undirected
   b. Directed
   c. Mixed

11. Distances and times
    a. Measured (tabulated)
    b. Estimated
    c. Mixed
    d. Stochastic
12. Objective
    a. Miminmize costs
    b. Minimize miles or hours
    c. Minimize number of trucks used
    d. Maximize utility (or gross profit)
    e. Balance workload
    f. Minimize use of outside carrier trucks
    g. Minimize risk

The above categories are neither exhaustive nor mutually exclusive. Every specific situation may have additional characteristics such as:

1. Delivery time windows*
2. Alternate sourcing of orders
3. Different product cost at alternate sources
4. Multiple types of products (commodities) and truck compartments
5. Loading/Unloading time as function of customer location and/or order size.
6. Depots without trucks
7. Order splitting between trucks*
8. Order splitting between sources

9. Product shortages at certain sources
10. Road congestion during certain hours*
11. Vehicle speed dependent on type of road
12. Roads with different weight limits
13. Transshipment between trucks (satellite distribution)
14. Calling precedence requirements (forced sequencing)
15. Trucks do not return to their origin*
16. Providing enough work to outside carriers (period commitment)
17. Special terms of operation of carrier trucks (e.g., geographical constraints)
18. Compatibility between truck and order
19. Compatibility between truck and loading/delivery site
20. Drivers as salesmen.
21. Coordinated routes (truck follows salesman)
22. "All or nothing" use of trucks
23. Scheduled delivery*

The characteristics marked by an asterisk were discussed by Schrage (1981). This list of properties is quite comprehensive and covers most practical truck routing problems. One should not expect all possible combinations of these characteristics to appear in practice, but their large number indicates the vast variability in truck routing and scheduling problems.

3. Relation to other problems

Truck routing and scheduling is not done in a vacuum. Strategic and tactical decisions set the stage for truck routing, and truck routing and scheduling imposes requirements on driver scheduling, and truck loading/unloading schedules.

The distribution system design process determines the number and location of the various facilities such as: plants, warehouses, truck depots and inbound consolidation centers. These locations affect the demand for trucking services. Perl and Daskin (1985) tried to account for this relation by formulating the combined location-routing problem as a mixed integer program, decomposing it into three subproblems and solving them sequentially using heuristics.

Fleet size and mix decisions determine the own fleet available for routing at any given time. Demand for trucking services usually changes daily, in very few environments is it constant (even then only for relatively short periods of time). Thus, fleet size and mix decisions are usually based on some average demand. If demand variability is known, (i.e., distribution of daily requirement for trucks) marginal analysis similar to that used in single period inventory models may be used to determine the fleet size. Such an analysis will not be straightforward because it depends on many assumptions concerning cost factors and efficiency of dispatching. When the fleet under the operators control is insufficient, some of the work may be given to carrier trucks or to common carriers (at a cost). Models of the relations between fleet size and mix, and truck routing were suggested by Golden et al. (1984) and Etezadi and Beasley (1983), but demand variability was not considered. The fleet size and mix problem when a common carrier option exists has been discussed by Ball et al. (1983). Fleet operators are trying to reduce demand variability and to improve dispatching efficiency by scheduling deliveries to a given customer on a given day(s) of the week ("scheduled delivery") or by shipping orders earlier than required, when possible and economical. Models for routing in a scheduled delivery context were discussed by Christofides and Beasley (1984) and Tan and Beasley (1984). Both used heuristics and did not consider demand variability.

Truck routing and scheduling is related to inventory problems through the set of orders to be delivered. Frequent delivery of small shipments is more expensive but reduces inventory costs. This relation was discussed by Burns et al. (1985). Federgruen and Zipkin (1984) presented a model for allocating a scarce commodity while taking into account truck routing and inventory shortage costs.

All the above mentioned models associate the short-term (operational) truck routing and scheduling decisions with longer term (strategic and tactical) decisions, and therefore usually look at some kind of "average" routes, without accounting for the daily variability in them, or its effects. Consideration of variability in demand for transportation services over time in a truck routing environment is not easy. A first step in considering such variability may be taken by simulating any proposed approach on past operational data. Explicit consideration of variability in such models is much harder due to the complexities introduced by statistical functions into models which are already based on assumptions that are not necessarily satisfied in practice.

4. Practical Aspects

Several practical aspects appear often in many truck routing and scheduling problems and deserve further elaboration:

a. Soft constraints -Several types of constraints in a problem may be soft, i.e., they may be violated to some extent at some cost without causing damage. For example, delivery time windows may be flexible, or the limit on the number of hours a truck may be used may be violated by several minutes, allowing an additional efficient delivery without causing any significant damage. Sometimes even specified weight limits may be violated to a small extent to allow efficient delivery (these approaches are actually applied in practice).

b. Demand variability -Demand from one period to the next is seldom the same. Thus, a new routing and scheduling problem must be solved each period. Although a subset of a master route may be used (according to the demand for the specific period) this approach is not necessarily efficient and often requires manual adjustments.

c. Multiple objectives -Transportation managers often want to make deliveries not only at minimal cost while meeting customer service requirements, but also in a balanced manner. For example, they are concerned with balancing workload between their own trucks, they don't want to give too much work to outside carriers, and they may have additional considerations which may be situation-specific. All these objectives must be balanced against each other in order to arrive at a satisfactory dispatch.

Consider a concrete example of a non-trivial truck routing and scheduling problem. A national corporation in the United States has 6 manufacturing plants located in different major metropolitan areas. Each plant manufactures common products which it distributes in its region, specialty products which it ships to customers nationwide, and specialty intermediate products which it ships to other plants for further processing (a specialty product is manufactured by one plant only). Next to each plant there is a truck depot with a fleet of company trucks which are used to deliver the products to customers and other plants, to bring materials and packaging from vendors, and to return empty packaging from customers. The private fleet is limited by management policy to one-day radius, i.e. the trucks must return at night to their home. In addition to the private fleet the company uses trucks of dedicated carriers which operate only in the "commercial zone" (about 40 km radius from the city center), and long-haul (interstate) carriers which haul only to destinations out of that state, and do not return at the shippers expense. Any shipment that is not assigned to one of the three types of trucks listed above may be given to a common carrier at a known cost. The cost structure of the various types of trucks is provided in Table 1. The trucks differ also in their sizes and some other physical characteristics.

INSERT TABLE 1

Order-truck compatability is determined by physical characteristics of the truck and requirements of the order, terms of employment of the truck (geographical limitations), and management policy (e.g., keep truck close to depot). In this operation each depot has to deliver and pick up orders that weigh anywhere from 10 kg. to 20 tons (a truckload) with destinations from 5 to 5,000 km. away. Each order has a "latest shipping date" but if the products are available in inventory the order may be shipped earlier, provided it is economical to do so. Thus, the orders for a given day are divided into two categories, those that must be shipped and those that may be shipped. Management likes to make the deliveries/pick-ups at minimum cost while balancing workload (hours and number of stops) among company trucks, uses company trucks before giving work to carriers, and does not ship too many orders too early (in order not to "starve" company trucks in future days). It must be evident that routing and scheduling decisions in this case must be made on cost basis due to the different costs of the various types of trucks. Some of the objectives are conflicting with others and the management is essentially looking for a "good" balanced solution, which is usually the case in practical problems.

5. Solution Approaches

Several different approaches have been used for solving truck routing and scheduling problems, and they are:

a. Manual methods. Putting together routes and schedules manually may not be easy, and may result not in the best solution, but still may be acceptable, especially where the operation is not large (i.e. there is only small potential for cost savings from using more elaborate methods). Manual methods are often combined with some aids, such as a pins on maps, Gantt charts or index cards (Bartholdi and Platzman (1982)). The use of manual methods inspires heuristics and facilities direct understanding of the various trade-offs involved.

b. Optimization. Pure optimal solutions are impractical for even simplified versions of truck routing problems of any practical size, unless the problem has a special structure. Even then, a powerful highly specialized solver is needed. Most optimization efforts try to minimize miles, hours or the number of trucks used, all these are proxy variables for cost which cannot be tackled directly. Some optimization models derive bounds on the value of the optimal solution and stop when the value of any solution is within a given tolerance from these bounds. A major question in this approach is the quality of the bounds.

c. Optimization with embedded heuristics. In order to facilitate good solutions to optimization models some heuristic rules are embedded in the models, thus allowing their solution within a reasonable time (e.g. Brown et al. (1987), Bell et al. (1983), Brown and Graves (1981)). Usually in these cases the optimization models themselves are not comprehensive enough to encompass all the intricacies of the original problem, thus their solutions need adjustments to make them acceptable to the dispatcher and the management. These adustments are usually done by heuristics ("tail end heuristics"). Although recent efforts have tried to solve problems with more practical aspects using optimization with embedded heuristics (i.e., time windows, backhauls, order-truck compatability) these models are still limited in scope and their integration into a unified framework is not expected any time soon.

d. Heuristics. Heuristics are, at the current time, necessary to provide satisfactory solutions to practical truck routing and scheduling problems. Heuristics have been widely discussed and their use have been legitimized in view of the inability of pure optimization methods to provide solutions to practical problems (see Ball and Magazine (1981), Muller-Merbach (1981) and Zanakis (1981)). The major problem with heuristics is that the quality of the derived solution is usually unknown, since there is no "benchmark" to compare it to. Efforts were made to provide bounds on heuristic solutions (Haimovich and Rinnooy-Kan (1985)), but the problems dealt with are more of a theoretical nature. Another problem is the lack of direct sensitivity analysis, although manually changing the solution and observing the resulting changes in the objectives may suffice.

The philosophical question whether it is better to optimally solve a subset of the real problem and adjust that optimal solution to fit the practical problem, or is it more advantageous to tackle the whole problem with methods that do not assure optimal solutions, will not be resolved easily.

A major disadvantage of most published work in truck routing and scheduling (and of existing software packages) is that they do not consider cost directly. Usually they try to minimize miles, hours or number of vehicles used, which are proxy variables for cost. This approach may be acceptable when dealing with a uniform fleet where all trucks are identical in physical and cost characteristics, but very often this is not the case. When an operation is run with a uniform fleet, one may suspect that due to variability of daily demand for transportation services, cost savings are possible from reducing the fleet size and using carrier trucks during periods of higher demand. Cost is not considered explicity in most models because it is harder to measure and much harder to incorporate different cost structures into the models (e.g., minimum rates, point to point rates, stop charges, rate per mile based on farthest destination of the route).

Since most truck dispatching problems are multi-objective, and since the dispatcher is the final judge concerning the quality of the solution, it has been suggested that he should be provided with easy-to-use tools to adjust (improve) the solution provided by a computer. Such tools must be interactive and well understood by the dispatcher. Daskin (1985) claims that "...the development of effective interactive (man/machine) optimization techniques is an exciting research area. Such techniques can simultaneously exploit a person's intuition and understanding of the problem and a computer's ability to process information quickly. The resulting solutions are more likely to be implementable than are those obtained without human interaction because (a) exogenous factors may be incorporated in the process, and (b) the analyst is likely to have greater confidence in the solutions".

It is suggested that cost-based <u>interactive</u> <u>heuristics</u> may do the job. A set of heuristic modules may be provided, each performing a basic heuristic operation with parameters controlled by the dispatcher. Several such modules and some parameters are described in Table 2. These heuristics may be designed to make changes in the schedule only if these changes result in cost reduction (taking into account penalties for violation of soft constraints).

INSERT TABLE 2

The dispatcher may invoke one heuristic at a time, with the desired control parameters, based on the type of improvements he envisions in the latest schedule displayed to him (or he may return to any former schedule and continue from there). The number of times to invoke each heuristic, their sequence and control parameters, are left to the dispatcher. Obviously it will be better to begin with a good solution which may be achieved by a pre-set sequence of heuristics applied to the initial solution (which may be derived by optimization, provided it is a feasible solution to the real problem at hand).

The option to assign specific orders to trucks, regardless of cost, should be included in such a dispatching environment, in order to facilitate inclusion of considerations beyond costs, and to increase the acceptability of the result. In addition it allows analysis of the senitivity of the solution to the specified changes.

The area of routing and scheduling may be one where human intelligence may prove superior to an artificial one, when the right tools are put in the hands of the human dispatcher, especially in view of the dynamic business environment.

One major problem with such an approach is model calibration. The relative sizes of the penalties (on violation of soft constraints) determine the quality of the solution provided by the interactive heuristics. It requires some experimentation with the values of the penalties to achieve satisfactory solution composition. Ideally, interactive heuristics should be tied with graphical presentation of solutions for better comprehension of the results (see Belardo (1985)), although a solution may be tightly constrained (in truck capacity utilization or time limits) and then not many improvements can be envisioned from observing the graphical representation.

The provision of detailed costs of each activity in a solution allows better comprehension of the economies of the situation and enhances the acceptability of the results.

In cases where it is not desirable to leave the activation of such interactive heuristics to the dispatcher (sequence, number of applications and tunings parameters) it may be left to the corporate analyst level, and the sequence may be frozen upon installation in a specific site. In such a case it should be verified that the frozen sequence of heuristics is robust, and provides good results under wide variety of scenarios.

The proposed approach of interactive heuristics (but without the graphics component) was tested on an IBM PC/AT using the formerly described problem with several hundred orders and up to 30 trucks of different types with very encouraging results (Rosenthal (1986)).

6. Software Design

The complexity of truck routing and scheduling problems usually makes it impractical to get good solutions in a manual fashion. Manual methods allow a good dispatcher to search for an acceptable feasible solution based on general guidelines ("rules of thumb") usually without looking at the economies of the specific situation (because the required data is not available to him or he does not have the time to calculate alternatives). Computerization of the dispatching process is often indispensable for achieving good solutions. If done properly, computerization allows easy generation and comparison of alternate dispatches, and may result in significant cost savings. Users look for many desirable features in a software package for truck routing and scheduling, most of the common ones are provided in Table 3. Some of these features contradict others, and obviously cannot be achieved in a single package. Users often find out that they got more than they bargained for (but will not admit it openly), thus one should be aware of some undesired features which may cripple the application.

INSERT TABLE 3

Truck routing and scheduling software can be implemented on microcomputers but then the major problem becomes timely updating of the order data. In larger organizations order data is usually available on another computer system, thus requiring data communication between the microcomputer and that system.

In cases where distances and times are not known from accounting standards (or when these standards are questionable), a geo-reference system may be useful to calculate distances between locations and to account for natural barriers and other obstacles on the road network. (e.g., ice on certain roads). Three different basic types of geo-reference systems are used. On one extreme is a full representation of the road network, where road intersections are nodes and road segments are arcs, and every location is connected to the network. This type of system requires large amounts of input data to build the network, and the drivers will not necessarily follow the shortest route between any two locations. On the other end is a representation of locations (and barriers) by their coordinates, and distance calculations based on straight line (or great circle). The calculated distances must be inflated by 25-40% to compensate for roads availability and curvature, and the resulting distance is by no means accurate (see Cooper (1983)), but data requirements are minimal. A compromise between these two extremes is a zone system, where map locations are divided into small zones (several km. across). Each location is associated with a zone, and distances are calculated between zone centers, based on adjacency relations between zones (i.e., to get from zone A to zone B the shortest sequence of zones that must be crossed is found). In a zone system it is easy to assign truck weight limits and driving speeds to each zone (this will require much more work in a full road networks, and is practically impossible in a coordinate system).

In cases where the cost savings potential is significant, a more advanced specialized truck routing and scheduling system may be integrated in an information system where data communication with other components of the information system (orders data base, truck terminals) is automated. (e.g. Brown et al. (1987)).

7. Summary

The complexity and wide variety of practical truck routing and scheduling problems often precludes pure optimal solutions. Optimization with embedded heuristics may be used to achieve good initial solutions to practical problems, but these solutions usually require adjustments to reflect practical aspects not included in the optimization model. Heuristics are indispensible in achieving good solutions to such problems but they should be controlled by an intelligent human who is acquainted with the operational environment and is aware of the desired objectives. Costs must be considered in routing and scheduling decisions. Heuristic modules activated interactively by a human dispatcher which improve scheduling based on cost savings are feasible and practical. Graphical representation of solutions enhances their appeal and acceptance. Such interactive heuristics, which combine the human dispatcher's understanding of the problem with the computer's calculation ability, offer hope for better results and wider applicability of truck routing and scheduling software packages and justify further research.

TABLE 1

COST STRUCTURE OF TRUCKS

Truck Type	Cost Type: Sunk Cost	Set-Up Cost	Cost Per Mile	Cost Per Hour	Point to Point	Cost Per Stop
Private Fleet	Fleet ownership	Driver's Wage	Gas, oil maintenance	Overtime		
Dedicated* Carrier		Min.hours /min. miles	+	+		
Interstate Carrier		Minimum Miles	Determined by final Destination			+
Common Carrier					Depends on origin, destination, weight	

*Operates in commercial zone only.

TABLE 2

SOME INTERACTIVE HEURISTIC MODULES

Heuristic	Level	Parameters
Move - from one truck to another	single order, group of orders, full load	From truck type, to truck type, only orders of type
Switch - between trucks	single orders, group of orders, full loads	Between trucks of types..., only orders of type
Delete - orders	single orders, group of orders, full loads	type of truck, type of order
Insert - orders	single orders	into type of truck, type of orders
Traveling - salesman		type of truck

TABLE 3

DESIRABLE TRUCK ROUTING PACKAGE FEATURES

° Ready Now, Off-The-Shelf

° Micro-Based, with Mainframe Interface

° Inexpensive

° Minimum Training and External Support

° Minimizes Miles, Vehicles, and Costs at Same Time

° Extremely Fast Solution Times

° Easy to use Manual Overrides and Extensive Graphics

° Extensive Tailored Reports

° Single and Multiple Depots (if needed)

° Pickups and Deliveries

° Manual or Automated Order Entry

° Single and Multiple Day Schedules

° Customer Time Windows

° Meets all Physical and Legal Constraints on Time, Weight, and Volume

° Makes Owned vs Hired Decisions

° Satisfies Labor Union Requirements

° Detailed and Flexible Geo-reference System

° Recognizes all Physical and Traffic Barriers

° Single and Multiple Compartments on Vehicles

SOME UNDESIRABLE FEATURES

° Requires crippling simplifications

° Costs more than it saves

° Gives unstable results

° Operates unreliably

° No support is provided by the system developer

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